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Prospects of green roofs in urban Thailand – A multi-criteria decision analysis

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A B S T R A C T

Green roof systems are considered a best practice for climate change adaptation and mitigation in urban areas affected by heat waves and stormwater flooding. Green roofs mitigate urban heat islands, improve urban air quality, buffer stormwater and improve runoff quality, absorb emissions and increase the thermal efficiency of buildings. Green roofs therefore are an interesting technology for densely populated urban areas in Thailand, but still at a rather low diffusion stage. The aim of this paper thus is to identify and quantify the main factors that influence green roof adoption using a mixed-method research design. The relevant factors were (1) identified in a qualitative content analysis, (2) structured alongside two dimensions (internal/external and positive/negative factors), and (3) quantitatively assessed in an Analytical Hierarchy Process based on expert judgments. The analysis yields three main factors influencing the diffusion potential of green roofs in Thailand: While their potential to mitigate urban heat islands is the most important facilitating factor, the lack of proper subsidy schemes as well as the lack of knowledge and skilled workforce, represent major adoption barriers. In spite of the discussed challenges and issues, a light trend towards greener buildings can already be observed among planners, architects, and also on policy levels in Thailand. If the identified issues are addressed properly, green roofs eventually could become a significant contributor to climate change mitigation and adaptation efforts in Thailand.

1. Introduction

1.1. Green infrastructure and climate change

Climate change and rapid urbanization impose major challenges on cities and call for sustainable urban development (Tripathi et al., 2014; Zhou et al., 2014). The United Nations' Sustainable Development Goal #11 ('Sustainable Cities and Communities') explicitly targets the environmental impact of cities, including resource efficiency, disaster resilience as well as mitigation and adaptation to climate change.[1]

One key issue intensified by climate change is the increase of temperatures in urban areas (Kiesel et al., 2012). This is especially relevant in the tropical and sub-tropical climate zones, where urban heat islands require additional cooling to keep indoor temperatures at acceptable comfort levels (Li and Norford, 2016). For example, in the tropical climate of Malaysia as much as 45% of electricity consumption in residential houses relates to cooling and air-conditioning (Elias and Lin, 2015). As energy systems and electricity generation still heavily rely on fossil fuels, active cooling systems account for a considerable amount of greenhouse gases (Koo et al., 2014) and thus exacerbate climate change.

One way to counteract urban heat island effects is the large-scale deployment of green infrastructure such as green spaces, parks, trees or greened buildings (Aflaki et al., 2017). Green infrastructure has been found effective in reducing near-surface temperatures during the night time (Li and Norford, 2016), with positive effects on human thermal comfort in the early morning;

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significant cooling potential during daytime has been reported as well (Razzaghmanesh et al., 2016). Strategic implementation of green infrastructure delivers additional environmental benefits to urban areas, most notably pollution reduction (Norton et al., 2015), bio-diversity increase (Benvenuti, 2014) and improvements in micro-climate through evaporative cooling (Coutts et al., 2013). Deploying green infrastructure thus can be understood as a useful element in climate change adaptation strategies (Aflaki et al., 2017; Norton et al., 2015; Razzaghmanesh et al., 2016), and as a potential measure for climate change mitigation due to the carbon fixation in plants (Getter et al., 2009).

Green roofs are of specific interest and relevance in this context. Roof areas often remain unused, and therefore greening does not require additional space, while similar benefits can be provided as with other type of green infrastructure. Green roofs thus are considered a best practice which provides heat island mitigation, increased thermal comforts for occupants (especially in upper-level condominiums) and decreased energy consumption. Furthermore, green roofs may even provide aesthetic value, especially when compared to flat concrete roofs (Saadatian et al., 2013). Due to their multiple benefits, green roofs are considered a 'sustainable construction practice' (Bianchini and Hewage, 2012b). For cities in hot and humid (sub-)tropics, in particular with high population density, green roofs are an interesting technology; however, the diffusion of green roofs is still in a rather early stage.

1.2. Adoption of green roofs

Green roofs have been proposed and adopted in countries with different climatic conditions (Berardi et al., 2014). While green roofs have a long history in Norway or Germany, and exhibit remarkable longevity (Köhler and Poll, 2010), they today also begin to receive attention among planners, researchers and policy makers in countries with hot and humid climates. As green roofs promise answers to several challenges which contemporary cities are facing, e.g. heat and extreme weather events, air pollution and soil sealing, this comes as no big surprise. Studies from Singapore (Li and Norford, 2016) or Hong Kong (Jim, 2015) already reported green roof benefits in hot humid regions, e.g. urban heat island reduction and decrease of cooling demand.

While green roofs thus promise to be a suitable tool for climate change adaptation (especially in terms of urban heat), their potential for climate change mitigation should not be underestimated either. South-East Asia is an economically growing region with rapid urbanization tendencies (Schneider et al., 2015), and therefore a highly relevant target for mitigation strategies. Green roofs certainly are a possible contribution. Currently, Singapore is leading with regards to green roof adoption in this region, with more than 60ha of green roofs on more than 500 buildings (Li and Norford, 2016). In Malaysia, growing interest in green building technology and green roofs can be observed as well, and the number of green roof projects is rapidly growing (Rahman et al., 2013). Research attention for green roofs, particularly in developing, or newly industrialized countries of Asia, is still limited (Vijayaraghavan, 2016). In addition, the adoption of green roofs is subject to contextual factors, including economic situation, climatic conditions, building characteristics, or nature of possible plantation, to name just a few (Semaan and Pearce, 2016; Vijayaraghavan, 2016).

1.3. Study case and aim of the paper

In Thailand, interest in green roofs so far can mainly be observed among architects. The possibility of integrating 'natural design' and green roofs into building concepts has recently been recognized by the Association of Siamese Architects under Royal Patronage (ASA). Also, the 2016 design awards were awarded to projects which included green infrastructure elements and green roofs. Nonetheless, the number of green roofs is comparably low in Thailand; despite the potential benefits a larger-scale adoption of green roofs would have, they so far only receive little attention by practitioners, policy makers and academics.

Factors which may stimulate and hinder green roof adoption in Thailand have not yet been systematically investigated. The aim of this paper therefore is to identify and assess concrete factors which influence the adoption of green roofs in Thailand. The focus of this case study is on the situation in Thailand, as perceived by green roof experts. A comparison with other countries is beyond the scope of this paper.

While the benefits of green roofs are well established in the literature, less attention was so far given to factors that may hinder the dissemination of green roof technology, or to external factors that affect their dissemination potential in one way or another. Therefore we followed a mixed-method approach to identify the factors that facilitate and hinder wide-spread adoption of green roofs using a qualitative problem structuring method, and quantitatively assessed them with an established multi-criteria decision analysis method. The hybrid SWOT/AHP approach was introduced by (Kurttila et al., 2000) and this approach applies the Analytic Hierarchy Process, or in short AHP (Saaty, 1980, 1986, 1999), to come up with a relative priority ranking of SWOT factors. Combining SWOT (as problem structuring method) and AHP (as multi-criteria decision analysis method) for such purpose is getting increasingly popular (Marttunen et al., 2017); it has been applied in several case studies, e.g. to assess technologies such as agricultural biogas (Brudermann et al., 2015), biofuels (Chanthawong and Dhakal, 2016) or photovoltaics (Reinsberger et al., 2015).

The remainder of the paper is structured as follows: In the subsequent section, we outline the methodological approach of this study. Section three involves four subsections; in Section 3.1 the main factors which could be identified are discussed; in Section 3.2, these factors are ranked based on expert judgments in an Analytical Hierarchy Process (AHP). Section 3.3 summarizes how the different respondent groups ranked the SWOT factors, and Section 3.4 features a discussion of possible strategies and implications. Section 4 offers an outlook on potential avenues for further research and

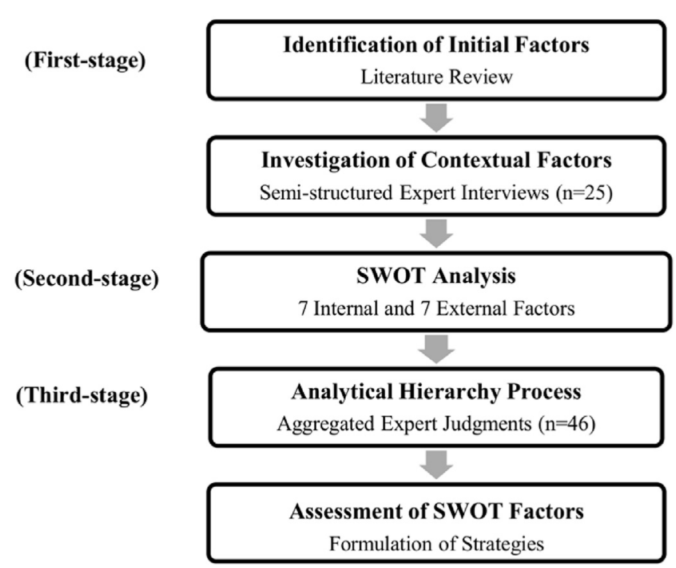

Fig. 1. Methodological framework of the study.

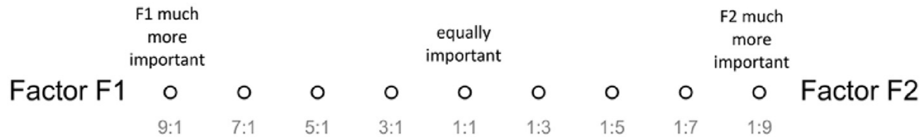

Fig. 2. Scale for pair-wise comparisons in AHP.

concludes the paper.

2. Methods

The study was implemented in a three-stage study design. In the first stage, possible contextual decision factors were identified based on a literature review and interviews with experts; in a second stage these factors were structured into a SWOT (strengths, weaknesses, opportunities and threats) framework; in the third stage, these factors were weighted by applying an empirically grounded Analytical Hierarchy Process (AHP) as shown in Fig. 1.

2.1. Identification of factors

Factors reported in a previous study (Brudermann and Sangkakool, 2017) served as a starting point; as this previous study focused on European cities with temperate climate under completely different economic, cultural and climatic circumstances, the list of factors however had to be thoroughly revised for the case of cities in Thailand. This revision was based semi-structured interviews with Thai experts ($n = 25$) of different backgrounds and expertise on green roofs. The interviews have been conducted with experts from the Bangkok area and Southern Thailand. Most of the interviewees (11) had a background in urban planning and architecture, but the sample also included nine academic experts as well as adopters and policy and city representatives. All architects in the sample were members of the Association of Siamese Architects (ASA); policy representatives were from provincial administrative offices and sub-district municipalities.

During the interviews, the list of decision factors, as identified in (Brudermann and Sangkakool, 2017), were introduced to the experts and discussed further to assess their relevance in the context of Thailand. In addition, a number of contextual issues with emphasis on hot and humid climates (e.g. Malaysia, Singapore and Thailand) also were openly discussed. The expert discussions generated a holistic view of the important factors related to green-roof adoption; the interviews were transcribed and subsequently analyzed using qualitative content analysis (Mayring, 2014). In this process, a few factors initially identified from the literature were discarded and a few were modified. Finally, a set of 14 relevant decision factors in the Thailand context were selected. Details on the selection of relevant factors are depicted in Supplement A.

2.2. SWOT analysis

In a second step, the identified factors were summarized and structured into a SWOT (strengths, weaknesses, opportunities, threats) framework. The SWOT framework distinguishes between internal factors directly related to a technology (strengths and weaknesses) and external factors which originate from the environment and cannot be influenced directly, but affect the success of a technology (opportunities and threats). Eventually, four strengths, three weaknesses, four opportunities and three threats were considered. Strengths and weaknesses of green roofs are well documented and therefore the expert statements could be backed-up with scientific literature. External influences, i.e. opportunities and threats in the SWOT framework, are highly context-specific, as discussed in the previous section, and rarely discussed in the literature. Therefore the statements of experts in semi-structured interviews served as the main source for identifying the most relevant opportunities for and threats to green roofs in the case of Thailand.

Table 1
Background of respondents in AHP survey.

Background	Number of initial respondents	Respondents passing quality check
Academics	17	5
Architects	50	20
Landscapers & planners	17	6
Others	36	15

2.3. Analytical Hierarchy Process (AHP)

In step three, these factors were ranked by using the Analytical Hierarchy Process (AHP). AHP is based on pairwise comparisons of factors on a 9-level ratio scale; respondents in an AHP survey were asked to pair-wisely compare all factors within the same category (i.e. Strength 1 with Strength 2, Strength 1 and Strength 3, etc., see Fig. 2), and to subsequently also pair-wisely compare the main categories (i.e. Strengths and Weaknesses, Strengths and Opportunities, etc.). The comparisons were transferred into a judgment matrix, and the relative priorities of the factors were derived by calculating the right principal Eigenvector of the multiplied matrices of these judgment matrices. Eventually, 24 pair-wise comparisons were necessary[2] for processing with AHP. A detailed description of this method is given by (Posch et al., 2015) and not repeated here.

To assess the identified factors via such pairwise comparisons, another expert sample was recruited between May and July 2016 during three topically relevant conferences organized by the Association of Siamese Architects (ASA), namely the ASA Dhaksin Forum 2016 in Hat Yai (approx. 200 participants, mainly landscapers, planners, architects and company representatives), the ASA Dhaksin seminar on Building Legislation and Regulation in Krabi (approx. 200 national participants, mainly architects working in the private and public sector), and the ASA congress on Green and Sustainable Architecture in Hat Yai (approx. 120 participants, mainly architects and real estate group representatives). Partakers with expertise on green roofs were asked to participate in the AHP-survey, and we managed to recruit 120 participants (see Table 1), to whom we explained the purpose of the study and handed over a printed questionnaire with pair-wise comparisons.

The collected questionnaires were checked for completeness and consistency, using the consistency ratio (CR) measure as

[2] This number comes about as follows: Four factors demand for six pairwise comparisons; three factors demand for three pairwise comparisons. Two SWOT groups consisted of four factors (2×6 comparisons), and two SWOT groups consisted of three factors (2×3 comparisons). The four SWOT groups were also compared pair-wisely (6 additional comparisons; $2 \times 6+2 \times 3+6 = 24$).

suggested by (Saaty, 1986). Assessments which contained grave inconsistencies in at least one of the judgment matrices were discarded and not used for further analysis. After this quality check, the assessments of 46 respondents (38.3%) could be utilized for further analysis (see Table 1). The judgments were aggregated using the geometric mean and then further processed with AHP to calculate the relative factor priorities as described in (Posch et al., 2015). This process yielded relative local priorities (lp) of factors compared to the other factors within the same SWOT group and relative SWOT group priorities (p) (e.g. the relative priority of the Strength group compared to Weaknesses, Opportunities and Threats). The global priorities (gp) of factors were calculated by simply multiplying relative local priorities of factors with the respective relative group priorities.

Finally, the consistency ratio was calculated for all aggregated judgments. A sufficient level of consistency ($CR < 10\%$) was found for the aggregated judgments as reported in Table 2.

2.4. Limitations

The chosen approach and the study described here are of course subject to limitations. A SWOT analysis is a qualitative approach and depends on the judgments of the researchers involved; the SWOT factors however were backed-up in the expert interviews. AHP allows adding a quantitative component to the analysis, but comes with limitations as well. Apart from technical limitations (Ishizaka and Labib, 2009), note that only a limited number of factors could be considered for processing with AHP, and hence SWOT factors sometimes had to be aggregated and condensed. Assessing an exhaustive list of factors is not feasible in an empirical SWOT/AHP study because the necessary pair-wise comparisons are not respondent-friendly. Instead they can be rather tiresome and lead to drop-outs, especially if a high number of comparisons are requested. AHP is suitable to derive factor priorities from expert assessments; however, the results are dependent on the participants. While the sample size ($n = 120$, 38% valid responses) is sufficient for an expert sample, and similar to sample sizes in other SWOT/AHP studies, the results are not claimed to be representative for all green roof experts in the country due to the chosen sampling strategy and focus on planners' and architects' perspectives. Being aware of these shortcomings, we nonetheless claim that the chosen approach allows us spotting the most important propensities; i.e. the most and least important factors for dissemination of green roofs in Thai cities could be identified based on the ranking, and are reported in the following section.

3. Results & discussion

3.1. SWOT analysis

In this section, the factors identified in semi-structured expert interviews and scientific literature are discussed and structured alongside a classical SWOT framework (positive/negative and internal/external). Note that in this study, we aim for a rather general view and therefore do not distinguish between different types of green roofs (intensive/extensive).

Table 2
Consistency ratios (CR) of pair-wise comparisons in AHP.

Comparisons (number)	CR
Strengths (6)	0.12%
Weaknesses (3)	1.19%
Opportunities (6)	1.26%
Threats (3)	2.69%
SWOT groups (6)	1.09%

3.1.1. Strengths

Strengths are internal positive factors, i.e. positive factors directly related to the product or technology. General strengths of green roofs are well documented in literature. In our semi-structured interviews we focused on green roofs strengths with respect to the situation in Thailand.

One of these strengths mentioned by almost all interviewees is green roofs' contribution to energy savings [S1], as they improve the building insulation and less thermal energy is lost through the roofs. While in many European cities these savings to a large degree are realized due to reduced heating demand in the winter time, green roofs reduce cooling demand in hot humid climates by providing insulation. Through the so called evapotranspiration effect incoming thermal (solar) energy evaporates the humidity stored in the plants and growing medium, and is not directly transformed into sensible heat stored in the roof material, as it is the case with traditional roofs (Getter and Rowe, 2006; Tabares-Velasco et al., 2012). Green roofs therefore act as a thermal buffer (Kokogiannakis and Darkwa, 2014) and reduce energy consumption in various climates (Hashemi et al., 2015; Refahi and Talkhabi, 2015); however their contribution to energy efficiency also relies on the overall insulation strategy of the building (La Roche and Berardi, 2014).

Another frequently reported and obvious strength is the eco-friendliness of green roofs [S2]. Most interviewees, and many published studies are enthusiastic about the manifold environmental benefits. Green roofs contribute to improved air quality, as they absorb dust particles, and have the potential to increase urban biodiversity by serving as habitat for birds, insects or wildflowers (Benvenuti, 2014; Madre et al., 2013). Green roofs also improve stormwater runoff and water quality (Gregoire and Clausen, 2011) and, compared to traditional roofs, also exhibit a better eco-balance over their entire life span; however, there is still room for improvement when it, e.g., comes to selection of materials for layers (Bianchini and Hewage, 2012a). Furthermore the quality of stormwater runoff in tropic climates is significantly improved as well (Hashemi et al., 2015). Green roofs also buffer rainwater, delay runoffs and thus mitigate the risk of flooding. While this particular strength received a lot of attention in a European expert sample (Brudermann and Sangkakool, 2017), it was not very much highlighted by the Thai expert sample in this study. The interviewed experts discussed runoff management as just one of the many environmental benefits. When it comes to rainwater buffering, more emphasis was put on challenges related to drainage systems of green roofs and concerns regarding statics (high dead loads) and potential damage/leakage (see the discussion of weaknesses below).

Apart from being considered a sustainable approach for runoff management, green roofs are also associated with aesthetical value and improvements in urban quality [S3] (Hashemi et al., 2015; Jungels et al., 2013). Intensive green roofs also can serve as recreational area (see example in Fig. 3), and especially architects in the expert sample highlighted the aesthetical factor, as natural elements can be elegantly integrated into urban design. Existing examples include green roof top bars on a few of the high-rise buildings in Bangkok; these aesthetically attractive lighthouse projects (possibly inspired by role models from Singapore) are considered especially important in the current early dissemination stage.

Another strength that is particularly relevant for hot climates is green roofs' ability to mitigate urban heat islands (UHI) [S4]. This aspect received strong emphasis from the experts as a separate factor in the context of Thailand, although existing studies often

Fig. 3. Intensive green roofs used as recreational area in Prince of Songkhla Hospital, Thailand.

classified this as one of the common environmental benefits green roof systems offer. In general, the intensity of UHI is affected by a city's geographical location, climatic conditions as well as seasonal variations (Mohajerani et al., 2017). For example, in hot summers and medium to low latitude cities, UHI impacts significantly urban air quality and thermal discomforts of the city dwellers (Aflaki et al., 2017). Promising results have been reported in numerous studies conducted in regions with hot climate or hot seasons, e.g. in Mediterranean climate regions (Razzaghmanesh et al., 2016; Zinzi and Agnoli, 2012), as well as in sub-tropical (Jim, 2015; Takebayashi and Moriyama, 2007) and tropical regions (Li and Norford, 2016). The cooling effect is a result of the evapotranspiration effect mentioned before; by the same token green roofs positively affect the neighborhood microclimate (Peng and Jim, 2013) and improve comfort in urban environments (Santamouris, 2014).

3.1.2. Weaknesses

Weaknesses are internal negative factors, i.e. negative factors directly related to green roof technology. One obvious weakness is the higher investment volume [W1] in comparison to ordinary roofs (Carter and Keeler, 2008; Refahi and Talkhabi, 2015). Although partly compensated by the reduced cooling demand later, a high upfront investment of course is a major barrier. If environmental benefits such as mitigation of air pollution are included in the economic valuation of green roofs, this weakness would be mitigated (Clark et al., 2008).

Another weakness of green roofs is that they require more maintenance [W2] than ordinary roofs (Carter and Keeler, 2008; Seidl et al., 2013). The vegetation (e.g. grass) needs to be cut from time to time, and it may be necessary to remove dead or undesired plants which grow on the roof due to seed dispersal (Berndtsson, 2010; Williams et al., 2010). Fertilization and irrigation (in the dry season between December and March) are additional issues that need to be taken into account. In overall, the climatic conditions in Thailand however are much more favorable for green roofs than e.g. in Central Europe, as the weather is ideal for plant growth all over the year, and not much re-planting is required.

Finally, concerns have been mentioned regarding possible damage and leakages [W3] related to green roofs. This included challenges regarding structural aspects (Tsang and Jim, 2013) and the statics of the building due to high dead loads (Berardi et al., 2014), as well as damages in the water proof layer caused by the roots of (invasive) plants (Savi et al., 2013). These issues did not receive a lot of attention in the related European study, in which such concerns were described as a problem of the past (Brudermann and Sangkakool, 2017). The circumstances in a tropical climate however are different; especially the regular and extremely heavy rainfalls in the monsoon season – which also affect the thermal effectiveness of green roofs (Lin et al., 2013) – impose challenges to building drainage systems, and increase the likelihood of leakage. Several experts mentioned concerns that current drainage systems are not sufficient to exclude the risk of water leaks. Such concerns seem to be specific for the Thailand case. In comparison, a study from tropical Hong Kong indeed points out that retention under a heavy rainfall regime in the tropics is less effective; but even if green roof systems have reached full moisture storage capacity, remarkable peak reduction and peak delay could be achieved (Wong and Jim, 2014). Leakage risks do, to the best of the authors knowledge, not reveive particular attention in the academic literature.

3.1.3. Opportunities

Opportunities are external factors that are favorable for green roof technology in Thailand. One opportunity arises from recent and ongoing changes in regulations and legislation [O1] which are starting to have a positive effect on green roof uptakes. Ministerial regulations under the energy conservation promotion act of 1992 and its amendment of 2007 prescribe energy conservation principles for thermal transfer values in buildings (in overall and for roofs), the use of energy-efficient materials and active, but also passive design measures to attain thermal comfort inside buildings. Building construction regulations also demand for mandatory environmental impact assessments for newly constructed high rise buildings as well as condominiums with floor areas of over 4000 m^2. Regulations also prescribe a certain share of green areas on the building premises (depending on apartment sizes and number of bedrooms); green roofs are accounted for green areas.

Growing social and environmental responsibility [O2] was mentioned as a factor several times. An increase of awareness on social and environmental benefits among building owners has been reported by several interviewees, making voluntary green roof implementation more likely. Green roofs on commercial buildings might even generate financial benefits, e.g. when green roofs are used to communicate the eco-friendliness of a company through engagement in green and sustainable architecture, and therefore strengthen its socially/environmentally responsible reputation.

One further facilitator for future green roof projects is a general trend towards green buildings [O3]. This trend e.g. is represented 'TREES' (Thai's Rating of Energy and Environmental Sustainability) rating system, recently issued by the Thai Green Building Institute, which formulates criteria for sustainable buildings (Lohmeng et al., 2017). One of the criteria is urban heat island mitigation, including the consideration of green surface areas, green roofs and green walls. In addition, international building norms, including LEED (Leadership in Energy and Environmental Design), BCA (Building and Construction Authority) Green Mark and environmental impact assessments are increasingly being implemented as well.

Finally, ongoing climate change [O4] and its recognition by policy makers is also being mentioned as a potential 'opportunity' for green roof diffusion in Thailand, as adaptation measures are likely to gain relevance in the foreseeable future.

Other than in the European study (Brudermann and Sangkakool, 2017), public awareness has not been mentioned as a relevant opportunity by the interviewed experts. This factor therefore has not been included in the subsequent AHP assessment.

3.1.4. Threats

Threats are external negative factors that may hinder adoption of green roofs in Thailand. These factors cannot be influenced directly. One clear threat is the lack of subsidies [T1]. As one interviewee pointed out, the roof is the last part of a building that is completed – usually at a time when most of the available finances have been used up already. In the absence of subsidies, green roofs are unlikely to be realized and might be skipped even if planned initially.

Another important issue is the lack of respective skills and knowledge [T2]; green roofs are a rather new technology in Thailand, and most roof building companies do not yet offer green roofs in their portfolios. Lack of expert knowledge might even lead to badly implemented green roof projects and consequently undermine the image of green roofs as a reliable technology. In general, awareness on the potentials of green roofs is low in Thailand, also among potential adopters and users.

While these first two threats have been reported by (Brudermann and Sangkakool, 2017) in a similar way, the Thai experts also mention another external threat: Synthetic green roofs and materials (e.g. synthetic grass) are cheaper and easier to maintain [T3], but resemble the pleasant look of natural green elements. Synthetic materials such as artificial grass have been quite popular in Thailand, and are for example used in the roof areas of Prince of Songkla Hospital and Hatyai Hospital in Southern Thailand (Fig. 4a–d). These materials of course do not have any environmental benefits.

The Thai interviewees did not address the issue of legal and political constraints, such as incompatibility with prevailing urban planning strategies. Difficulties in integrating historical and modern architecture are also less an issue than, e.g., in protected city centers in European cities. These factors therefore have not been included in the AHP assessment.

Table 3 summarizes the SWOT factors. In the upcoming section, we report how these decision criteria have been quantitatively assessed by the experts participating in the Analytical Hierarchy Process (AHP).

3.2. Overall ranking of factors

AHP overcomes the main shortcoming of a SWOT analysis, which is its limitation to qualitative statements. In SWOT/AHP, the identified factors are being ranked with respect to their relevance for green roof adoption in Thailand. The summary of the AHP results is presented in Table 4. The detailed calculations are provided as Supplement B.

In the group of strengths, the potential of green roofs to contribute to urban heat island mitigation receives the highest ranking [lp(S4) = 0.36]. Energy savings [lp(S1) = 0.25] and environmental benefits [lp(S2) = 0.24] are considered less relevant. The factor 'aesthetics and urban quality' [lp(S3) = 0.15] receives the

Table 3
SWOT factors for green roofs in Thailand.

	Positive	Negative
Internal	*Strengths*	*Weaknesses*
	S1: Energy savings	W1: Investment volume
	S2: Environmental benefits	W2: Maintenance requirements
	S3: Aesthetics/urban quality	W3: Possible damage/leakage
	S4: Urban heat island mitigation	
External	*Opportunities*	*Threats*
	O1: Favorable regulations & policies	T1: Lack of subsidies
	O2: Social responsibility concerns	T2: Lack of skills and knowledge
	O3: Green building trends	T3: Cheap synthetic grass
	O4: Climate change	

Fig. 4. In one publically accessible area of Prince of Songkhla Hospital, natural green elements on roofs and courtyards have been replaced by synthetic materials.

Table 4
AHP ranking of SWOT factors.

SWOT Groups	Group priority	SWOT Factors		Aggregated Judgments (n = 46)			
				Local priority	Group ranking	Global priority	Global ranking
Strengths	0.28	S1	Energy savings	0.25	(2.)	0.071	(9.)
		S2	Environmental benefits	0.24	(3.)	0.067	(10.)
		S3	Aesthetics/urban quality	0.15	(4.)	0.043	(13.)
		S4	Urban heat island mitigation	0.36	(1.)	0.102	(2.)
Weaknesses	0.18	W1	Investment volume	0.41	(1.)	0.076	(6.)
		W2	Maintenance requirements	0.39	(2.)	0.072	(8.)
		W3	Possible damage/leakage	0.20	(3.)	0.037	(14.)
Opportunities	0.27	O1	Favorable regulations and policies	0.24	(3.)	0.064	(11.)
		O2	Social responsibility concerns	0.19	(4.)	0.051	(12.)
		O3	Green building trends	0.30	(1.)	0.082	(3.)
		O4	Climate change	0.27	(2.)	0.073	(7.)
Threats	0.26	T1	Lack of subsidies	0.39	(1.)	0.103	(1.)
		T2	Lack of skills and knowledge	0.31	(3.)	0.081	(5.)
		T3	Cheap synthetic grass	0.31	(2.)	0.081	(4.)

lowest score in this comparison. Although aesthetic satisfaction seems to be important in some study contexts, e.g. in Johannesburg, South Africa (Labuschagne and Zulch, 2016), it is often influenced by city dwellers' preference for 'green living style' (Zhang et al., 2012) and availability of climate-specific plant types and their longevity (Li and Yeung, 2014).

The high investment volume [lp(W1) = 0.41] and maintenance requirements [lp(W2) = 0.39] are considered as relevant weaknesses; possible damage and leakage [lp(W3) = 0.20] on the other hand score very low. This result is surprising insofar that the fear of damage and leakage, especially in the case of heavy tropical rainfalls, was clearly pointed out in the semi-structured qualitative interviews. The quantitative assessment however, in relative comparison to investment volume and maintenance requirements, puts this issue into perspective.

In the category of opportunities the result is not as clear, and none of the factors is particularly outstanding in the assessment. Green building trends [lp(O3) = 0.30] are seen as the most relevant opportunity for green roof diffusion in Thailand, followed by climate change [lp(O4) = 0.27]. Regulations and policies [lp(O1) = 0.24] receive a relatively low score and only rank third in the assessment, although proactive policy and regulatory support is especially considered in several developed and developing countries to increase green roof installations (Irga et al., 2017; Zhang et al., 2012). Moreover, presumed growing social responsibility concerns [lp(O2) = 0.19] are currently not seen as an important driver in Thailand. Rahman et al. (2013) also pointed lack of awareness about 'public greenery' among Malaysian citizens and eventually suggested that installing green roofs in the residential buildings for private use could be more effective.

Among possible threats to green roof diffusion, the evident lack of subsidy schemes [lp(T1) = 0.39] comes in first. Considering the necessary investment volume, this clearly is a major barrier. Lacking skills and knowledge [lp(T2) = 0.31] and competition from synthetic materials [lp(T3) = 0.31] receive lower but similar scores. Zhang et al. (2012) also concluded that lack of proper incentives and knowledge mobilization for residential building owners deemed to be important barriers in large-scale diffusion of green roof systems.

When comparing the relevance of SWOT groups, strengths [p(S) = 0.28], opportunities [p(O) = 0.27] and threats to green roof diffusion [p(T) = 0.26] receive similar ratings. Weaknesses of green roofs receive the lowest rating [p(W) = 0.18].

The global priority (gp) of a factor can be determined by simply multiplying the 'local priority (lp)' of a factor (the relative priority of the factor within the group) and the respective 'group priority (p)' (the relative priority of a SWOT group compared to the other SWOT groups). This procedure reveals the most important factors for green roof diffusion (Table 4): the lack of subsidy mechanisms [gp(T1) = 0.103] as the main negative factor and the ability to mitigate urban heat islands [gp(S1) = 0.102] as the main positive factor. Further top ranked factors are green building trends [gp(O3) = 0.082], competition from cheap synthetic materials [gp(T3) = 0.081], and lack of skills and knowledge [gp(T2) = 0.081].

Other factors are considered to be of medium or low importance for green roofs in Thailand; on the bottom end of the ranking, the three least relevant factors are the issue of possible damage & leakage [gp(W3) = 0.037], aesthetics and urban quality [gp(S3) = 0.043] and social responsibility concerns [gp(O2) = 0.051].

The global priorities of factors also are graphically illustrated in Fig. 5. Factors related to positive SWOT groups (Strengths and Opportunities) are plotted on the left side, whereas factors from negative SWOT groups (Weaknesses and Threats) lie on the right side. The overall graphical assessment of the SWOT factors in the context of Thailand also shows that external factors related to opportunities and threats (e.g. T1, T2, T3, O3) are slightly more relevant in diffusing green roofs than internal factors associated with strengths and weakness (e.g. S1, S2, S3, W3). In addition, fewer factors from the group of internal factors also have significant influences in either fostering (e.g. S4) or impeding (e.g. W1, W2) green roof diffusions in the urban areas of Thailand. Moreover, the diffusion perspectives of green roofs in developing countries like Thailand considerably differ from the context of European countries, where the positive factors were dominating over negative factors (Brudermann and Sangkakool, 2017).

3.3. Ranking of factors by different respondent groups

Looking at how the different respondent groups, i.e. academics, architects, landscapers/planners and others, rate the importance of the factors reveals substantial differences in perceptions.

With regards to strengths, the highest score is assigned to urban heat island mitigation by three of the four respondent groups [lp(S4) ranging from 0.30 to 0.44], while environmental benefits receive highest scores [lp(S2) = 0.36] from the academic experts. Agreement can be found with regards to the relevance of aesthetics and urban quality – this factor is considered the least important strength [lp(S3) ranging from 0.10 to 0.20].

With regards to weaknesses, respondent groups have different perspectives as well. Landscapers/planners and others consider

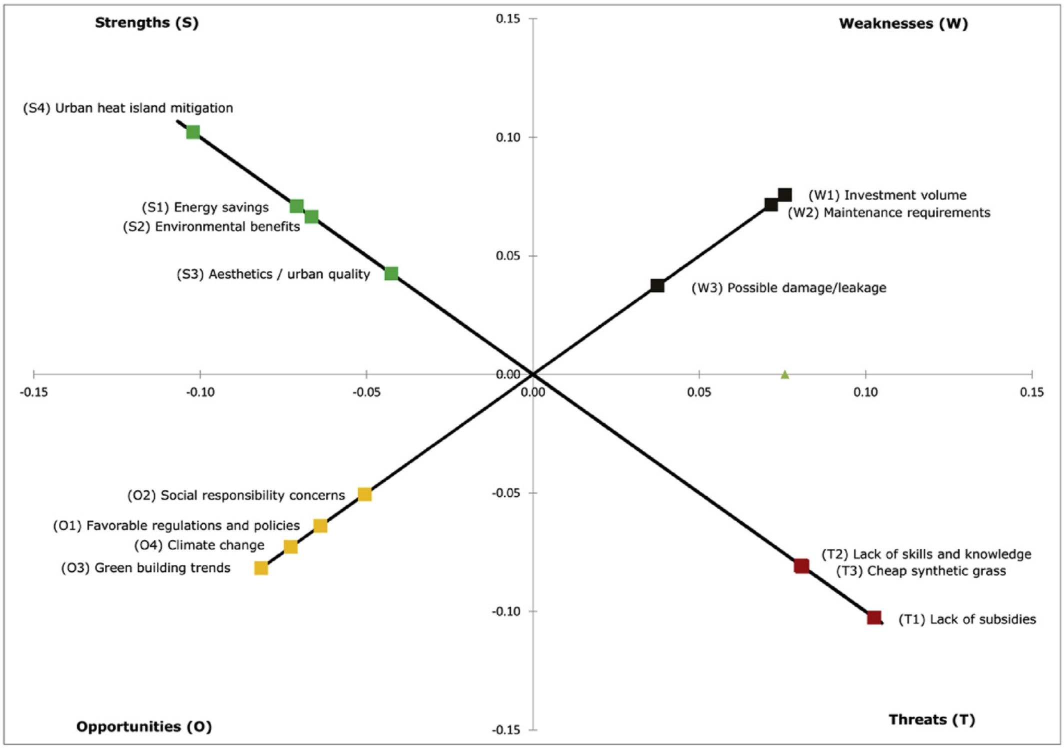

Fig. 5. Graphical illustration of SWOT factors with global priorities.

investment volume as the main weakness [lp(W1) = 0.40 and 0.49], while academics and architects see the maintenance requirements as more crucial [lp(W2) = 0.37 and 0.43]. Academics in the sample consider investment volume as the least relevant weakness [lp(W1) = 0.28], while possible damage and leakages [lp(W3) ranging from 0.17 to 0.25] scores lowest among weaknesses in the assessments by the other three respondent groups.

With regards to opportunities, favorable regulations and policies [lp(O1) = 0.33] come in first in the assessments by academics, while the other three groups put more emphasis on green building trends [lp(O3) ranging from 0.28 to 0.36]. All four respondent groups more or less agree that social responsibility concerns are relatively unimportant, and that climate change is a moderately important stimulus for green roofs.

With regards to threats to green roof diffusion, it is again the group of academics who disagrees with the other three groups concerning the most relevant factor. While academics see the lack of skills and knowledge [lp(T2) = 0.49] as crucial, the other groups consider the lack of subsidy scheme as the most relevant threat [lp(T1) ranging from 0.36 to 0.42]. Competition from cheap synthetic grass is not considered a serious threat by any of the groups.

With regards to SWOT group priorities, there is considerable disagreement. For academics, the strengths of green roofs are most relevant by far [p(S) = .42]. Architects also prioritize strengths, but on a less distinct mark [p(S) = 0.30]. For the group of others, the opportunities seem most relevant [p(O) = .31], closely followed by strengths [p(S) = 0.29]. The landscapers and planners strongly disagree with the prioritization of positive factors: They consider the threats as the most relevant SWOT group by far [p(T) = 0.47], and consider the strengths as relatively irrelevant [p(S) = 0.11]. Thus this group clearly is skeptical about the prospects of green roof diffusion in urban Thailand.

The differences in perspectives come as no big surprise. Different stakeholder groups vary in their level of technological understanding, knowledge and practical experiences; while, e.g., academics are often well informed about technological potentials, planners clearly have a practical focus and have a better understanding of implementation barriers. This particular difference is well pronounced in the factor rankings.

The results from the different respondent groups are detailed in Table 5. This table also includes an alternative aggregation of the expert responses, namely the arithmetic means of global priorities as reported by the different respondent groups. The most important factors for green roof adoption here turn out to be the lack of subsidy schemes [gp(T1) = 0.104], mitigation of urban heat islands [gp(S4) = 0.101], and limited skills and knowledge [gp(T2) = 0.092]. This different aggregation technique yields a very similar factor ranking as presented in Table 3, where all responses were aggregated using geometric mean. Only few factors switch their ranking (e.g., S2 and O3), thus indicating the robustness of the results.

3.4. Strategies for green roof diffusion

Based on the SWOT/AHP framework, it is possible to elaborate on strategies for green roof adoption in Thailand. One possible strategy is to utilize opportunities based on the strengths of the technology (O-S strategy). The climate change ‘opportunity’ – or more precisely, opportunities that arise from efforts to tackle climate change – can be directly addressed by green roofs: They contribute to the mitigation of urban heat islands and buffer extreme rainfalls. Outlining the eco-friendliness of the technology would furthermore pick up on the opportunity of green building trends. A second strategy involves the utilization of opportunities to overcome weaknesses (O-W); here, favorable laws and regulations might eventually help to overcome the main weaknesses, namely the investment volume and additional maintenance requirements. A third strategy arises from applying strengths to reduce the technology's vulnerability to threats (S-T); eco-

Table 5
AHP results for different respondent groups. The rightmost column indicates the aggregated results, i.e. the arithmetic mean of the global priorities reported by the different groups.

SWOT Factors		Academics (n = 5)			Architects (n = 20)			Landscapers & Planners (n = 6)			Others (n = 15)			Aggregated (n = 46)
		Local priority	Group priority	Global priority	Local priority	Group priority	Global priority	Local priority	Group priority	Global priority	Local priority	Group priority	Global priority	Global priority (ranking)
S1	Energy savings	0.20	0.42	0.09	0.25	0.30	0.08	0.18	0.11	0.02	0.28	0.29	0.08	0.067 (10.)
S2	Environmental benefits	0.36	0.42	0.15	0.25	0.30	0.08	0.27	0.11	0.03	0.17	0.29	0.05	0.077 (5.)
S3	Aesthetics	0.10	0.42	0.04	0.20	0.30	0.06	0.16	0.11	0.02	0.11	0.29	0.03	0.038 (14.)
S4	Urban heat island mitigation	0.34	0.42	0.14	0.30	0.30	0.09	0.39	0.11	0.04	0.44	0.29	0.13	0.101 (2.)
W1	Investment volume	0.28	0.16	0.04	0.38	0.24	0.09	0.40	0.19	0.07	0.49	0.12	0.06	0.068 (7.)
W2	Maintenance requirements	0.37	0.16	0.06	0.43	0.24	0.10	0.36	0.19	0.07	0.34	0.12	0.04	0.068 (8.)
W3	Possible damage/leakage	0.36	0.16	0.06	0.19	0.24	0.05	0.25	0.19	0.05	0.17	0.12	0.02	0.042 (13.)
O1	Favorable regulations and policies	0.33	0.24	0.08	0.28	0.24	0.07	0.16	0.23	0.04	0.19	0.31	0.06	0.060 (11.)
O2	Social responsibility concerns	0.20	0.24	0.05	0.17	0.24	0.04	0.24	0.23	0.06	0.19	0.31	0.06	0.050 (12.)
O3	Green building trends	0.22	0.24	0.05	0.28	0.24	0.07	0.36	0.23	0.08	0.34	0.31	0.10	0.077 (6.)
O4	Climate change	0.25	0.24	0.06	0.26	0.24	0.06	0.24	0.23	0.06	0.29	0.31	0.09	0.067 (9.)
T1	Lack of subsidies	0.30	0.18	0.05	0.42	0.22	0.09	0.36	0.47	0.17	0.38	0.28	0.11	0.104 (1.)
T2	Lack of skills and knowledge	0.49	0.18	0.09	0.26	0.22	0.06	0.30	0.47	0.14	0.32	0.28	0.09	0.092 (3.)
T3	Cheap synthetic grass	0.21	0.18	0.04	0.32	0.22	0.07	0.35	0.47	0.16	0.30	0.28	0.08	0.088 (4.)

friendliness for example is a main competitive advantage against cheaper synthetic materials, and the manifold environmental benefits could eventually be an argument for the introduction of subsidy schemes. Finally, contrasting weaknesses and threats (W-T) aids the formulation of a defense strategy; here, financial considerations are dominant, as activities like carrying out the necessary investments for green roofs, and covering the additional operating costs, are currently not incentivized by supportive schemes.

On a more general level, policy decisions will heavily influence the further adoption of green roofs in Thailand. Green roofs definitely are well suited to address some of the issues cities in tropical climates are facing on their long path to sustainable development. The humid tropical climate imposes certain challenges to the implementation of green roofs, e.g. heavy Monsoon rainfalls. On the other hand temperatures are favorable for plant growth and allow for greater variety with respect to used plants. Thus the main adoption barriers currently seem to be of financial nature.

Although green roofs certainly are a promising technology, the results of this multi-criteria decision analysis reveal a similar dilemma as in a related European study (Brudermann and Sangkakool, 2017). The dilemma results from the fact that many of the green roof benefits are felt by the general public, especially the beneficial effects on surface temperature and air quality, while the builders and owners bear investment risks and need to cope with higher financing requirements, without support in the form of subsidy schemes. In the AHP analysis this dilemma is represented by two top ranked factors, urban heat island reduction [S4] and lack of subsidies [T1]. This clearly is a practical limitation to green roof procurement which yet needs to be overcome. Other practical limitations such as lack of knowledge among potential adopters and planners, lack of skilled specialists, and lack of local manufacturers of green roof materials and elements need to be addressed as well. A current limitation to the sustainability performance of green roofs however is the use of polyethylene and polypropylene in foils and alternative materials are required to make green roofs more sustainable (Bianchini and Hewage, 2012a).

When discussing green spaces, green infrastructure and green roofs, the focus however should not exclusively be on financial aspects, like the higher investment volume for builders or additional government spending for subsidy schemes, but also on benefits and increases in value related to green roofs, and green infrastructure in general. Green infrastructure does not only provide intangible benefits, there are often also direct financial benefits. For example, proximity to a green belt is likely to increase house prices (Herath et al., 2015), and green infrastructure may provide cost savings even if indirect benefits are not considered (Jaffe, 2010). In a similar vein, buildings with green roofs may increase in value, or even upgrade entire neighborhoods, when seemingly intangible benefits like better air quality and more comfortable temperatures monetize into higher rents or apartment prices (which however has downsides as well).

4. Conclusions

In spite of the discussed challenges and issues, a light trend towards ‘greener’ buildings can already be observed among planners, architects, and also on policy levels in Thailand. The results of this study also suggest that potential weaknesses of green roofs are not overly relevant; technological problems are considered either insignificant or resolvable. Educational and promotional campaigns for builders, planners and architects however will be necessary to further stimulate green roof diffusion, as knowledge about green roofs in general, and also specific technical knowledge is not widely spread yet. Addressing these issues will certainly require considerable efforts, but eventually green roofs could become a significant contributor to climate change mitigation and adaptation efforts in Thailand.

This study was the first one to focus on factors that facilitate and hinder green roof adoption in Thailand and aimed for a quantification of the relative priorities of these factors. Therefore the findings of this study may inform green roof stakeholders in the development of dissemination strategies, and policy makers may take the outcomes as a guideline for policies related to greening of urban areas. Potential avenues for further research could be more

specific analyses on prospects of green roof adoption on regional and local levels, or concrete diffusion scenarios in dependence of different policy directions; another relevant line of research would be the question how to actively reduce adoption barriers and how to facilitate adoption by different types of adopters (commercial, private and public buildings; new buildings and refurbishment, etc.), and for different types of green roofs (extensive, intensive and semi-intensive green roofs). Research also could be extended to scenarios for urban heat reduction potential, and to how policy schemes in favor of green infrastructure could be designed efficiently.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2018.06.060.

References

Aflaki, A., Mirnezhad, M., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Omrany, H., Wang, Z.H., Akbari, H., 2017. Urban heat island mitigation strategies: a state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. Cities 62, 131–145. http://doi.org/10.1016/j.cities.2016.09.003.

Benvenuti, S., 2014. Wildflower green roofs for urban landscaping, ecological sustainability and biodiversity. Landsc. Urban Plann. 124, 151–161. http://doi.org/10.1016/j.landurbplan.2014.01.004.

Berardi, U., GhaffarianHoseini, A., GhaffarianHoseini, A., 2014. State-of-the-art analysis of the environmental benefits of green roofs. Appl. Energy 115, 411–428. http://doi.org/10.1016/j.apenergy.2013.10.047.

Berndtsson, J.C., 2010. Green roof performance towards management of runoff water quantity and quality: a review. Ecol. Eng. 36 (4), 351–360. http://doi.org/10.1016/j.ecoleng.2009.12.014.

Bianchini, F., Hewage, K., 2012a. How "green" are the green roofs? Lifecycle analysis of green roof materials. Build. Environ. 48 (1), 57–65. http://doi.org/10.1016/j.buildenv.2011.08.019.

Bianchini, F., Hewage, K., 2012b. Probabilistic social cost-benefit analysis for green roofs: a lifecycle approach. Build. Environ. 58, 152–162. http://doi.org/10.1016/j.buildenv.2012.07.005.

Brudermann, T., Mitterhuber, C., Posch, A., 2015. Agricultural biogas plants - a systematic analysis of strengths, weaknesses, opportunities and threats. Energy Pol. 76, 107–111. http://doi.org/10.1016/j.enpol.2014.11.022.

Brudermann, T., Sangkakool, T., 2017. Green roofs in temperate climate cities in Europe – an analysis of key decision factors. Urban For. Urban Green. 21, 224–234. http://doi.org/10.1016/j.ufug.2016.12.008.

Carter, T., Keeler, A., 2008. Life-cycle cost-benefit analysis of extensive vegetated roof systems. J. Environ. Manag. 87 (3), 350–363. http://doi.org/10.1016/j.jenvman.2007.01.024.

Chanthawong, A., Dhakal, S., 2016. Stakeholders' perceptions on challenges and opportunities for biodiesel and bioethanol policy development in Thailand. Energy Pol. 91, 189–206. http://doi.org/10.1016/j.enpol.2016.01.008.

Clark, C., Adriaens, P., Talbot, F.B., 2008. Green roof valuation: a probabilistic economic analysis of environmental benefits. Environ. Sci. Technol. 42 (6), 2155–2161. http://doi.org/10.1021/es0706652.

Coutts, A.M., Daly, E., Beringer, J., Tapper, N.J., 2013. Assessing practical measures to reduce urban heat: green and cool roofs. Build. Environ. 70, 266–276. http://doi.org/10.1016/j.buildenv.2013.08.021.

Elias, E.M., Lin, C.K., 2015. The empirical study of green buildings (Residential) implementation: perspective of house developers. Procedia Environ. Sci. 28, 708–716 (SustaiN 2014). http://doi.org/10.1016/j.proenv.2015.07.083.

Getter, K.L., Rowe, D.B., 2006. The role of extensive green roofs in sustainable development. Hortscience 41 (5), 1276–1285.

Getter, K.L., Rowe, D.B., Robertson, G.P., Cregg, B.M., Andresen, J.A., 2009. Carbon sequestration potential of extensive green roofs. Environ. Sci. Technol. 43 (19), 7564–7570. http://doi.org/10.1021/es901539x.

Gregoire, B.G., Clausen, J.C., 2011. Effect of a modular extensive green roof on stormwater runoff and water quality. Ecol. Eng. 37 (6), 963–969. http://doi.org/10.1016/j.ecoleng.2011.02.004.

Hashemi, S.S.G., Mahmud, H. Bin, Ashraf, M.A., 2015. Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: a review. Renew. Sustain. Energy Rev 52, 669–679. http://doi.org/10.1016/j.rser.2015.07.163.

Herath, S., Choumert, J., Maier, G., 2015. The value of the greenbelt in Vienna: a spatial hedonic analysis. Ann. Reg. Sci. 54 (2), 349–374. http://doi.org/10.1007/s00168-015-0657-1.

Irga, P.J., Braun, J.T., Douglas, A.N.J., Pettit, T., Fujiwara, S., Burchett, M.D., Torpy, F.R., 2017. The distribution of green walls and green roofs throughout Australia: do policy instruments influence the frequency of projects? Urban For. Urban Green. 24 (April), 164–174. http://doi.org/10.1016/j.ufug.2017.03.026.

Ishizaka, A., Labib, A., 2009. Analytic hierarchy process and expert choice: benefits and limitations. OR Insight 22 (4), 201–220. http://doi.org/10.1057/ori.2009.10.

Jaffe, M., 2010. Environmental reviews & case studies: reflections on green infrastructure economics. Environ. Pract. 12 (4), 357–365. http://doi.org/10.1017/S1466046610000475.

Jim, C.Y., 2015. Assessing climate-adaptation effect of extensive tropical green roofs in cities. Landsc. Urban Plann. 138, 54–70. http://doi.org/10.1016/j.landurbplan.2015.02.014.

Jungels, J., Rakow, D.A., Allred, S.B., Skelly, S.M., 2013. Attitudes and aesthetic reactions toward green roofs in the Northeastern United States. Landsc. Urban Plann. 117, 13–21. http://doi.org/10.1016/j.landurbplan.2013.04.013.

Kiesel, K., Orehounig, K., Shoshtari, S., Mahdavi, A., 2012. Urban heat island phenomenon in Central Europe. In: 1st International Conference on Architecture & Urban Design, vol. 1, pp. 821–828.

Köhler, M., Poll, P.H., 2010. Long-term performance of selected old Berlin greenroofs in comparison to younger extensive greenroofs in Berlin. Ecol. Eng. 36 (5), 722–729. http://doi.org/10.1016/j.ecoleng.2009.12.019.

Kokogiannakis, G., Darkwa, J., 2014. Support for the integration of green roof constructions within Chinese building energy performance policies. Energy 65, 71–79. http://doi.org/10.1016/j.energy.2013.11.076.

Koo, C., Park, S., Hong, T., Park, H.S., 2014. An estimation model for the heating and cooling demand of a residential building with a different envelope design using the finite element method. Appl. Energy 115, 205–215. http://doi.org/10.1016/j.apenergy.2013.11.014.

Kurttila, M., Pesonen, M., Kangas, J., Kajanus, M., 2000. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. For. Pol. Econ. 1 (1), 41–52. http://doi.org/10.1016/S1389-9341(99)00004-0.

La Roche, P., Berardi, U., 2014. Comfort and energy savings with active green roofs. Energy Build. 82, 492–504. http://doi.org/10.1016/j.enbuild.2014.07.055.

Labuschagne, P., Zulch, B., 2016. Green rooftop systems: a South African perspective. Energy Procedia 96, 710–716. October. http://doi.org/10.1016/j.egypro.2016.09.131.

Li, W.C., Yeung, K.K.A., 2014. A comprehensive study of green roof performance from environmental perspective. Int. J. Sustain. Built Environ. 3 (1), 127–134. http://doi.org/10.1016/j.ijsbe.2014.05.001.

Li, X.-X., Norford, L.K., 2016. Evaluation of cool roof and vegetations in mitigating urban heat island in a tropical city, Singapore. Urban Clim. 16, 59–74. http://doi.org/10.1016/j.uclim.2015.12.002.

Lin, B.-S., Yu, C.-C., Su, A.-T., Lin, Y.-J., 2013. Impact of climatic conditions on the thermal effectiveness of an extensive green roof. Build. Environ. 67, 26–33. http://doi.org/10.1016/j.buildenv.2013.04.026.

Lohmeng, A., Sudasna, K., Tondee, T., 2017. State of the art of green building standards and certification system development in Thailand. Energy Procedia 138, 417–422. http://doi.org/10.1016/j.egypro.2017.10.188.

Madre, F., Vergnes, A., Machon, N., Clergeau, P., 2013. A comparison of 3 types of green roof as habitats for arthropods. Ecol. Eng. 57, 109–117. http://doi.org/10.1016/j.ecoleng.2013.04.029.

Marttunen, M., Lienert, J., Belton, V., 2017. Structuring problems for Multi-Criteria Decision Analysis in practice: a literature review of method combinations. Eur. J. Oper. Res. 263 (1), 1–17. http://doi.org/10.1016/j.ejor.2017.04.041.

Mayring, P., 2014. Qualitative Content Analysis. Theoretical Foundation, Basic Procedures and Software Solution. Klagenfurt. Retrieved from. https://www.qcamap.org/.

Mohajerani, A., Bakaric, J., Jeffrey-Bailey, T., 2017. The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. J. Environ. Manag. 197, 522–538. http://doi.org/10.1016/j.jenvman.2017.03.095.

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S.G., 2015. Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landsc. Urban Plann. 134, 127–138. http://doi.org/10.1016/j.landurbplan.2014.10.018.

Peng, L.L.H., Jim, C.Y., 2013. Green-roof effects on neighborhood microclimate and human thermal sensation. Energies 6 (2), 598–618. http://doi.org/10.3390/en6020598.

Posch, A., Brudermann, T., Braschel, N., Gabriel, M., 2015. Strategic energy management in energy-intensive enterprises – a quantitative analysis of relevant factors in the Austrian paper and pulp industry. J. Clean. Prod. 90, 291–299. http://doi.org/10.1016/j.jclepro.2014.11.044.

Rahman, S.R.A., Ahmad, H., Rosley, M.S.F., 2013. Green roof: its awareness among professionals and potential in Malaysian market. Procedia - Soc. Behav. Sci. 85, 443–453. http://doi.org/10.1016/j.sbspro.2013.08.373.

Razzaghmanesh, M., Beecham, S., Salemi, T., 2016. The role of green roofs in mitigating Urban Heat Island effects in the metropolitan area of Adelaide, South Australia. Urban For. Urban Green. 15, 89–102. http://doi.org/10.1016/j.ufug.2015.11.013.

Refahi, A.H., Talkhabi, H., 2015. Investigating the effective factors on the reduction of energy consumption in residential buildings with green roofs. Renew. Energy 80, 595–603. http://doi.org/10.1016/j.renene.2015.02.030.

Reinsberger, K., Brudermann, T., Posch, A., 2015. The role of photovoltaics in energy transition – assessing the prospects for a regime shift. GAIA 24 (1), 49–55. https://doi.org/10.14512/gaia.24.1.10.

Saadatian, O., Sopian, K., Salleh, E., Lim, C.H., Riffat, S., Saadatian, E., Sulaiman, M.Y., 2013. A review of energy aspects of green roofs. Renew. Sustain. Energy Rev. 23, 155–168. http://doi.org/10.1016/j.rser.2013.02.022.

Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw- Hill, New York.

Saaty, T.L., 1986. Axiomatic foundation of the analytic hierarchy process. Manag. Sci. 32 (7), 841–855.

Saaty, T.L., 1999. Decision Making for Leaders. The Analytic Hierarchy Process for Decisions in a Complex World. RWS Publications, Pittsburgh, US.

Santamouris, M., 2014. Cooling the cities - a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. Sol. Energy 103, 682–703. http://doi.org/10.1016/j.solener.2012.07.003.

Savi, T., Andri, S., Nardini, A., 2013. Impact of different green roof layering on plant water status and drought survival. Ecol. Eng. 57, 188–196. http://doi.org/10.1016/j.ecoleng.2013.04.048.

Schneider, A., Mertes, C.M., Tatem, A.J., Tan, B., Sulla-Menashe, D., Graves, S.J., Dastur, A., 2015. A new urban landscape in East–Southeast Asia, 2000–2010. Environ. Res. Lett. 10 (3), 34002. http://doi.org/10.1088/1748-9326/10/3/034002.

Seidl, M., Gromaire, M.C., Saad, M., De Gouvello, B., 2013. Effect of substrate depth and rain-event history on the pollutant abatement of green roofs. Environ. Pollut. 183, 195–203. http://doi.org/10.1016/j.envpol.2013.05.026.

Semaan, M., Pearce, A., 2016. Assessment of the gains and benefits of green roofs in different climates. Procedia Eng. 145, 333–339. http://doi.org/10.1016/j.proeng.2016.04.083.

Tabares-Velasco, P.C., Zhao, M., Peterson, N., Srebric, J., Berghage, R., 2012. Validation of predictive heat and mass transfer green roof model with extensive green roof field data. Ecol. Eng. 47, 165–173. http://doi.org/10.1016/j.ecoleng.2012.06.012.

Takebayashi, H., Moriyama, M., 2007. Surface heat budget on green roof and high reflection roof for mitigation of urban heat island. Build. Environ. 42 (8), 2971–2979. http://doi.org/10.1016/j.buildenv.2006.06.017.

Tripathi, R., Sengupta, S.K., Patra, A., Chang, H., Jung, I.W., 2014. Climate change, urban development, and community perception of an extreme flood: a case study of Vernonia, Oregon, USA. Appl. Geogr. 46, 137–146. http://doi.org/10.1016/j.apgeog.2013.11.007.

Tsang, S.W., Jim, C.Y., 2013. A stochastic model to optimize forecast and fulfillment of green roof demand. Urban For. Urban Green. 12 (1), 53–60. http://doi.org/10.1016/j.ufug.2012.10.002.

Vijayaraghavan, K., 2016. Green roofs: a critical review on the role of components, benefits, limitations and trends. Renew. Sustain. Energy Rev. 57, 740–752. http://doi.org/10.1016/j.rser.2015.12.119.

Williams, N.S.G., Rayner, J.P., Raynor, K.J., 2010. Green roofs for a wide brown land: opportunities and barriers for rooftop greening in Australia. Urban For. Urban Green. 9 (3), 245–251. http://doi.org/10.1016/j.ufug.2010.01.005.

Wong, G.K.L., Jim, C.Y., 2014. Quantitative hydrologic performance of extensive green roof under humid-tropical rainfall regime. Ecol. Eng. 70, 366–378. http://doi.org/10.1016/j.ecoleng.2014.06.025.

Zhang, X., Shen, L., Tam, V.W.Y., Lee, W.W.Y., 2012. Barriers to implement extensive green roof systems: a Hong Kong study. Renew. Sustain. Energy Rev. 16 (1), 314–319. http://doi.org/10.1016/j.rser.2011.07.157.

Zhou, Y., Clarke, L., Eom, J., Kyle, P., Patel, P., Kim, S.H., Seiple, T., 2014. Modeling the effect of climate change on U.S. state-level buildings energy demands in an integrated assessment framework. Appl. Energy 113, 1077–1088. http://doi.org/10.1016/j.apenergy.2013.08.034.

Zinzi, M., Agnoli, S., 2012. Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. Energy Build. 55, 66–76. http://doi.org/10.1016/j.enbuild.2011.09.024.